

Noise-Temperature Measurements at NIST

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μCal Workshop, U. Maryland, 10/30/00

Outline

What we do (primarily):

- <Work is mostly in enclosed systems
- <Calibrate noise sources for customers
- <Develop & maintain primary standards
- <Develop measurement methods

How we do it:

- <Cryogenic primary standards
- <Total-power radiometers
- <Uncertainty Analysis

What else we do (recently):

- <Stability measurements
- <Adapter characterization
- <International comparisons

What we will do (in development):

- <Amplifier noise parameter measurements, especially for LNAs
- <On-wafer noise measurements
- <Higher frequencies

What We Do

Noise source calibrations; Waveguide:

Connector	Frequencies	Typical Expanded ($k = 2$) Uncertainties
WR-90	8.2–12.4 GHz	1.1%
WR-62	12.4–18 GHz	0.8%–0.9%
WR-42	18–26 GHz	0.8%–0.9%
WR-28	26.5–40 GHz	1.4%–1.7%
WR-22	33–50 GHz	1.6%–1.7%
WR-15	50–65 GHz	1.6%–1.7%

Uncertainties are “expanded” (2F, 95% c.l.) and are for noise temperatures around 10,000 K .

Noise Source Calibrations; Coaxial:

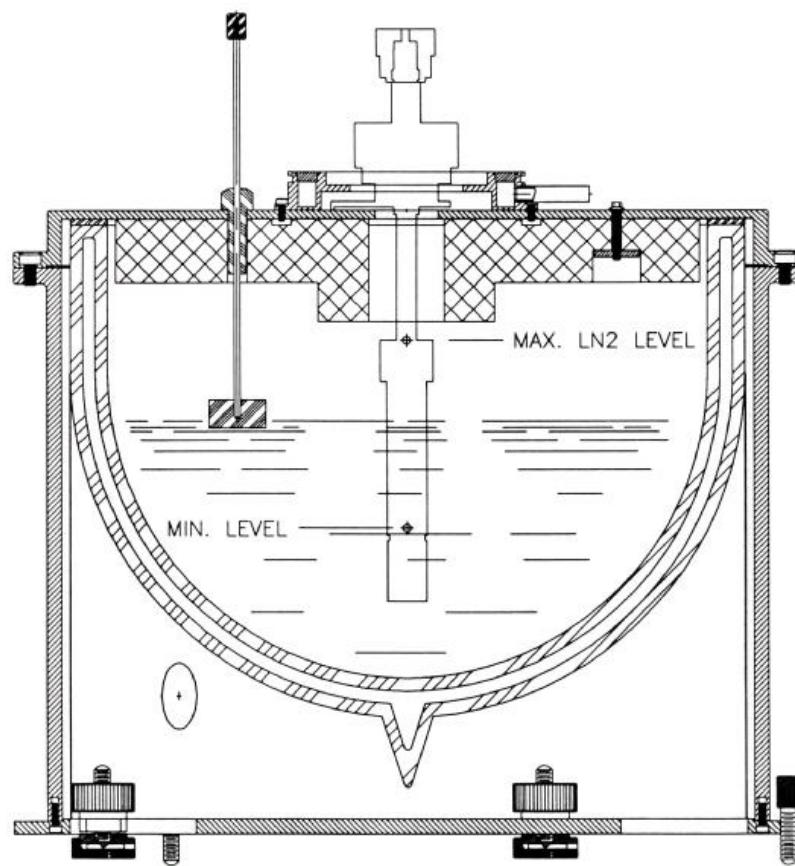
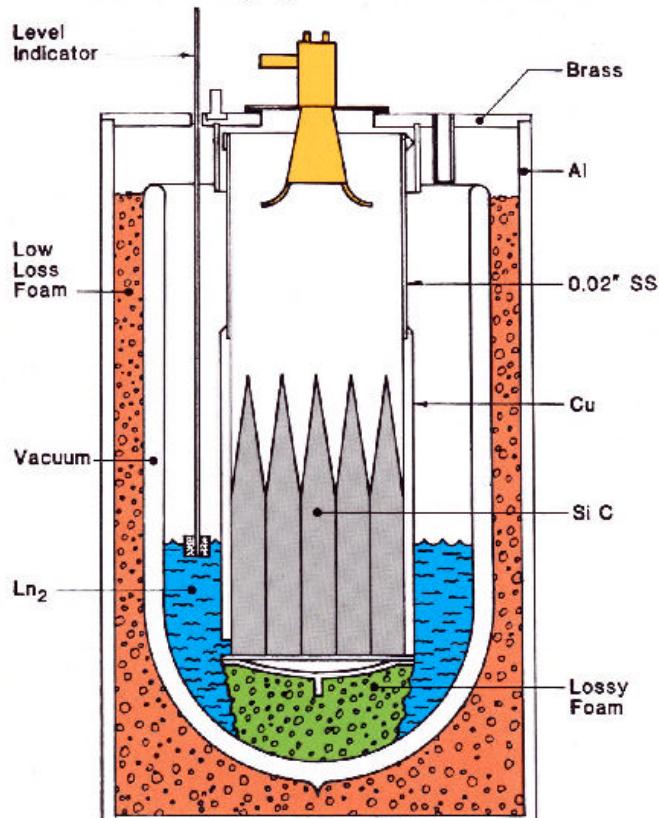
Connector	Frequencies	Typical Expanded ($k = 2$) Uncertainties
14 mm	30 & 60 MHz, 1–4 GHz	1 % – 1.4%
GPC-7	30 & 60 MHz, 1–12.4 GHz	1 % – 1.1%
	12.4–18 GHz	0.9%
N Precision	30 & 60 MHz, 1–18 GHz	1 % – 1.2%
3.5 mm	30 & 60 MHz	1.4%
	1–26 GHz	1 % – 1.2%
2.4 mm	8–12.4 GHz	1 % – 1.1%
	12.4–26 GHz	0.9% – 1.0%
	26.5–40 GHz	1.4% – 1.7%

Primary Standards

Ambient standard: matched load,
water jacket, thermistor, thermal
paste. $u_{Ta} = 0.1 \text{ K}$

Cryogenic standards; liquid nitrogen,
both coaxial & waveguide.
 $u_{Tc} . 0.2 \text{ K}$ (waveguide)
 0.6 K (coaxial)

94 GHz Cryogenic Noise Standard





Principal uncertainty components in primary standards:

<Coaxial:

- @ Temperature of load
- @ Reflections in line
- @ Temperature distribution of transition region (and variation with liquid nitrogen level)
- @ Skin loss effects

<Waveguide:

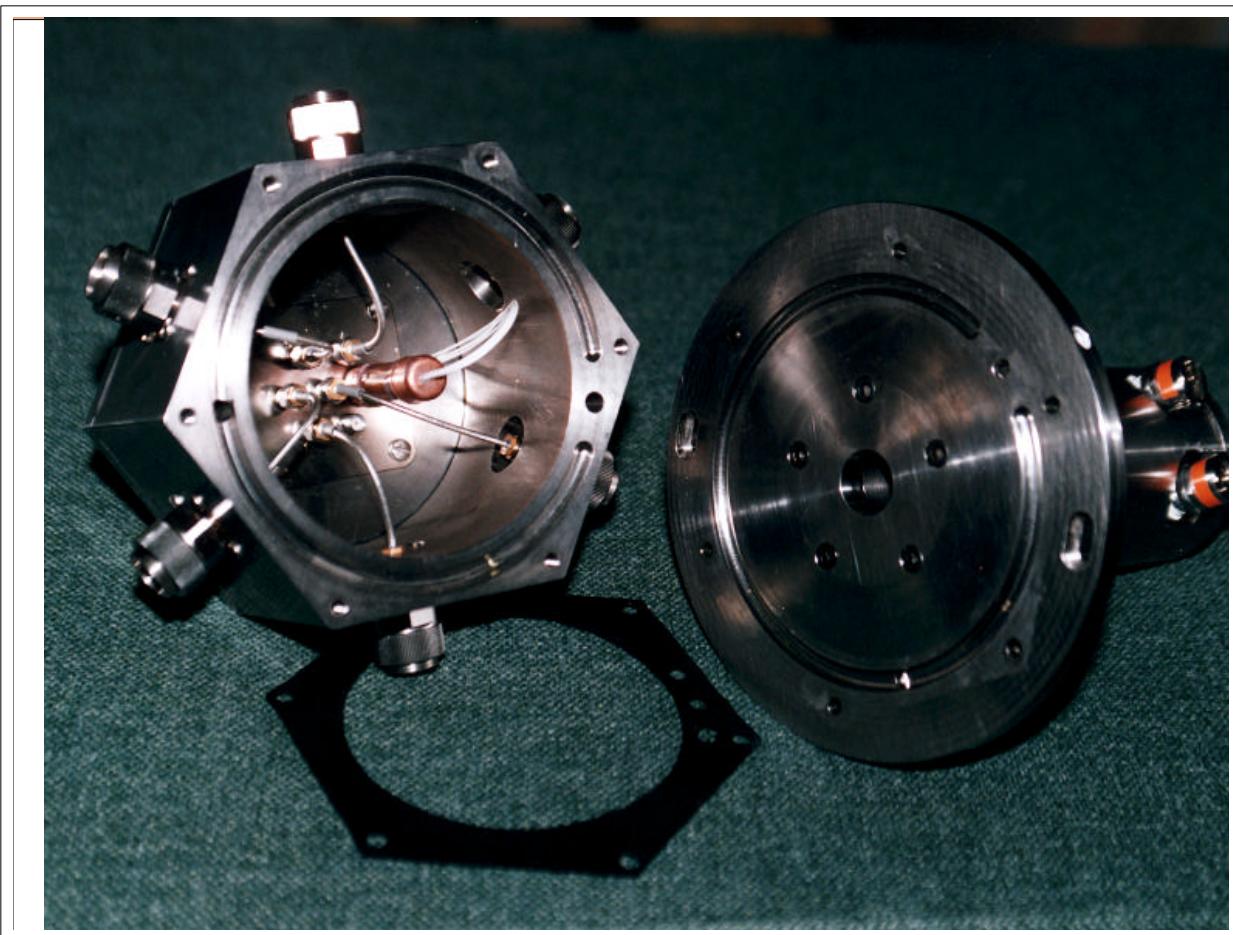
- @ Temperature of wedges
- @ Loss in horn (surface roughness)
- @ Excess cavity noise

Total-Power Radiometers

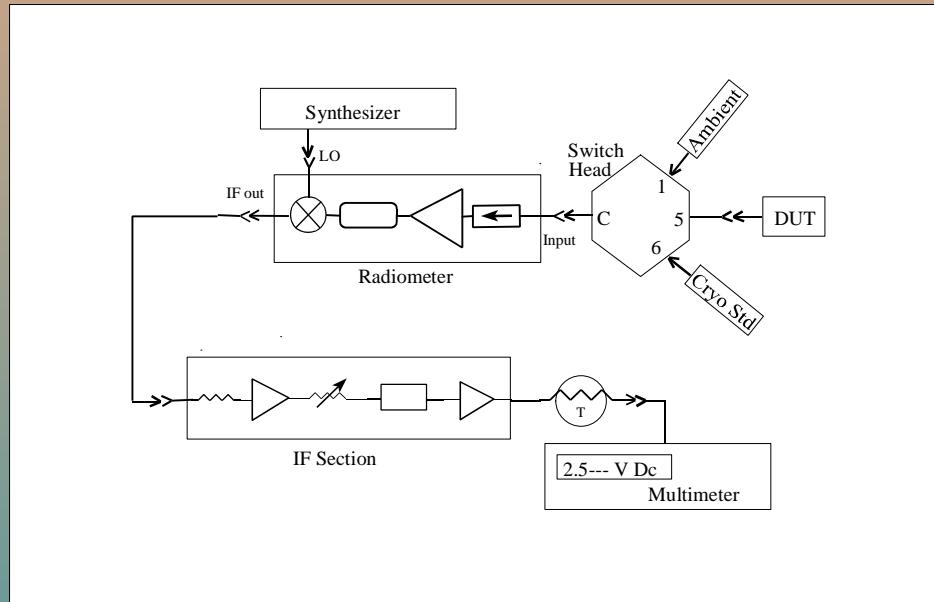
Two principal types: Coax & waveguide, with & without internal 6-port reflectometers.

At & above 1 GHz, all radiometers are isolated.

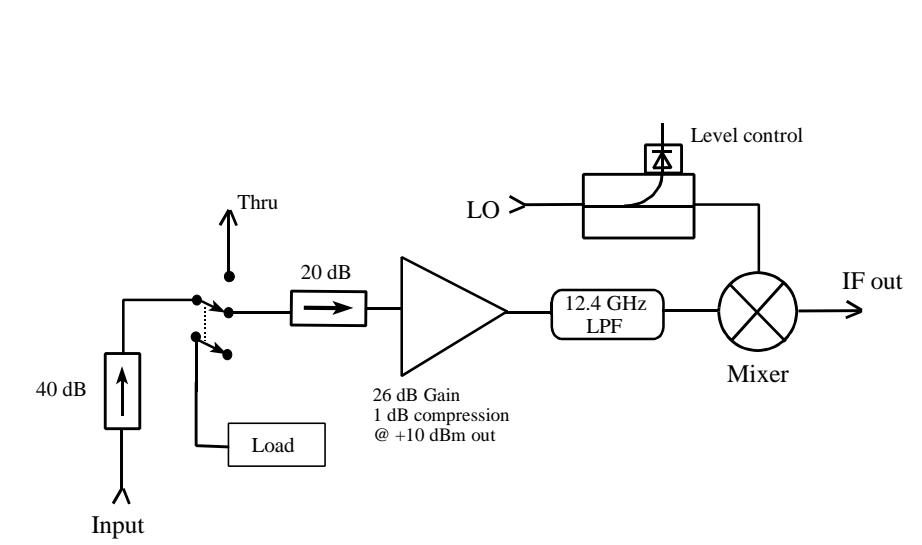
Water jackets or plates on anything lossy (isolators, switches, filters) or active (amps, mixer).



System Diagram



RF Section Diagram



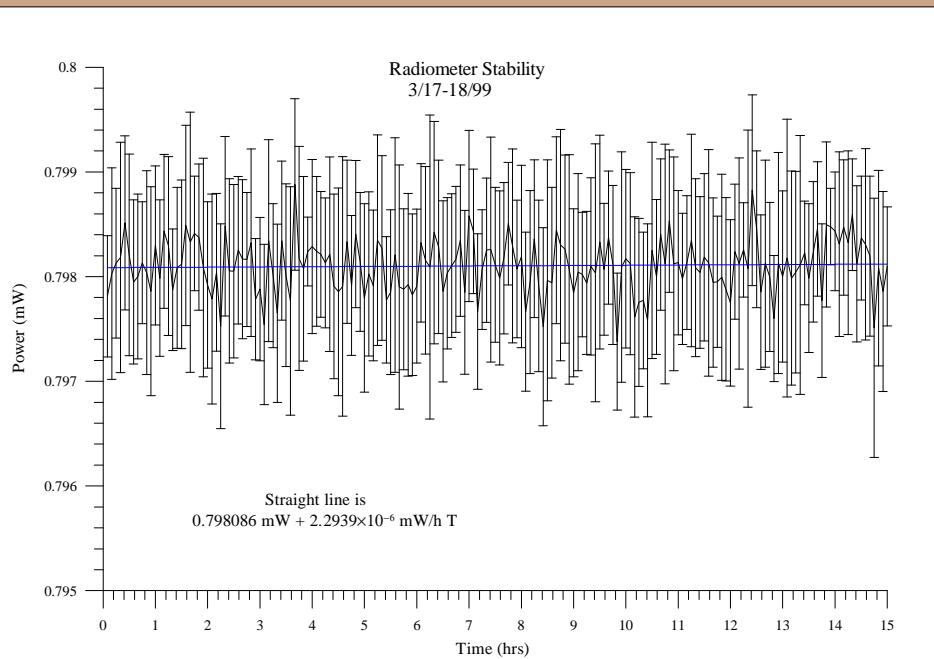
General system properties (8–12 GHz unit)

- <IF=2.5 MHz, BW=5 MHz, double sideband
- <Noise temperature . 450 K (at 8 GHz)
- <Gain . 100 dB
- <Sensitivity: Std. dev. of mean . 3 K at 9500 K, 50 readings; . 0.07 K at 296 K, 50 readings.

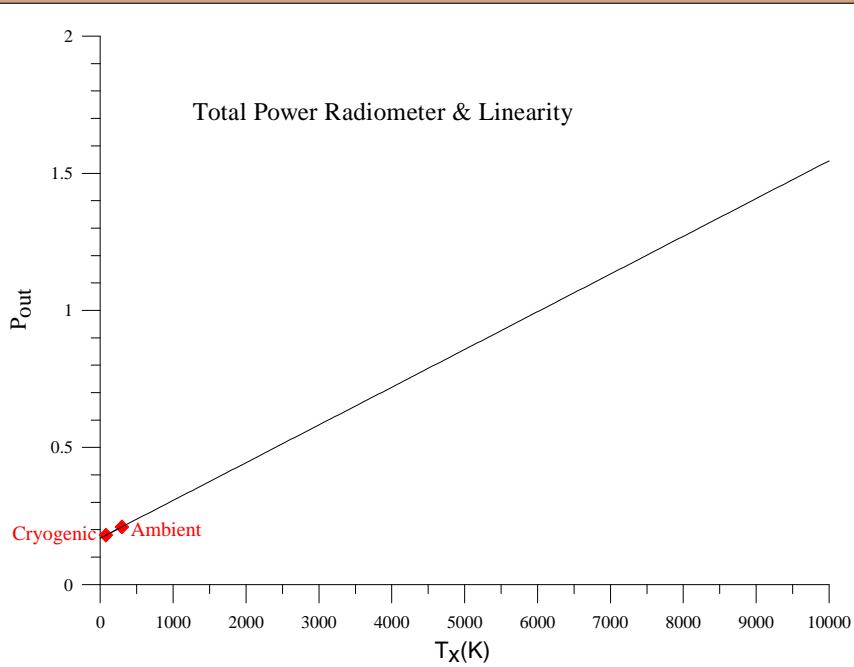
Tests & Checks

- <Stability
- <Isolation
- <Linearity
 - @ IF
 - @ Mixer
 - @ System
- <Spurious signals
- <Mismatch factors & asymmetries
- <Repeatability
- <Comparison to other systems (old system, band edges, international comparison sources.)

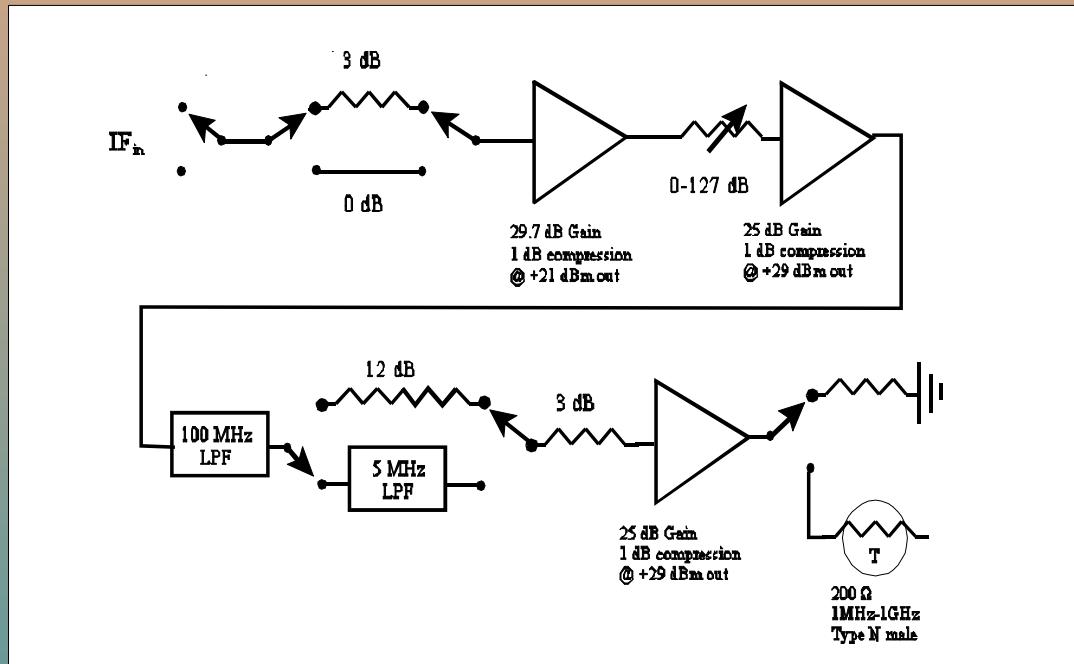
Typical Stability



Linearity



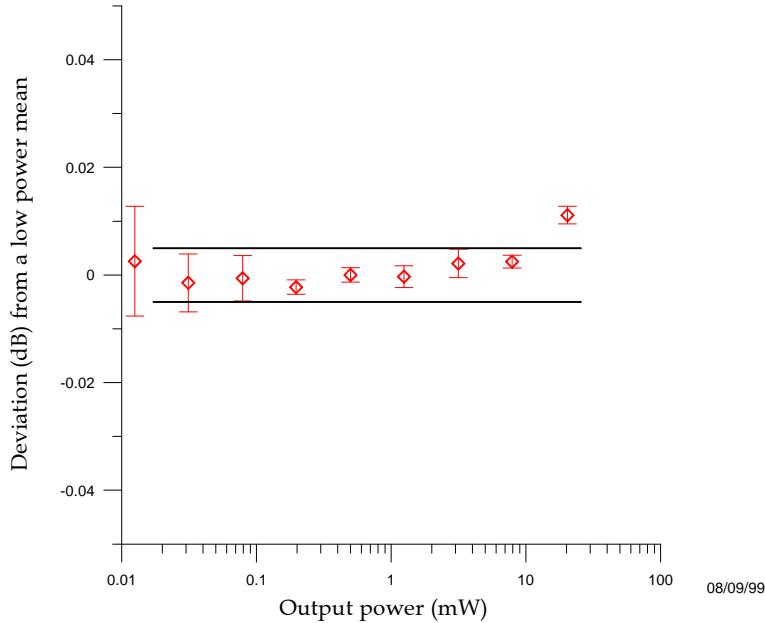
IF Linearity Test:



IF Linearity Test:

- < Measure with 3-dB attenuator in and out for range of 127 dB attenuator.
- < Plot $P_{out}(3 \text{ dB out})/P_{out}(3 \text{ dB in})$ as a functions of P_{out} .
- < Require it to be constant to within 0.1 % (0.005 dB).

IF Test Results:



Uncertainties

Radiometer equation:

$$T_x = T_a \frac{M_s 0_{02}}{M_x 0_{03}} \frac{(Y_x - 1)}{(Y_s - 1)} (T_s + T_a)$$

Type-B uncertainties:

Ambient Standard: $\frac{u_{T_x}(amb)}{T_x} \cdot \frac{T_x \& T_s}{\left| T_a \& T_s \right|} \frac{T_a}{T_x} \bar{u}_{T_a}, \quad \bar{u}_{T_a} \cdot \frac{0.1 K}{296 K} \cdot 0.034 \%$.

Cryogenic Standard: $\frac{u_{T_x}(Cry)}{T_x} \cdot \frac{\left| T_a \& T_s \right|}{T_x \left| T_a \& T_s \right|} \frac{u_{Cry}}{T_s}, \quad \frac{u_{Cry}}{T_s} \cdot 0.2 \% \text{ or } 0.8 \%$

Type-B Uncertainties (cont'd):

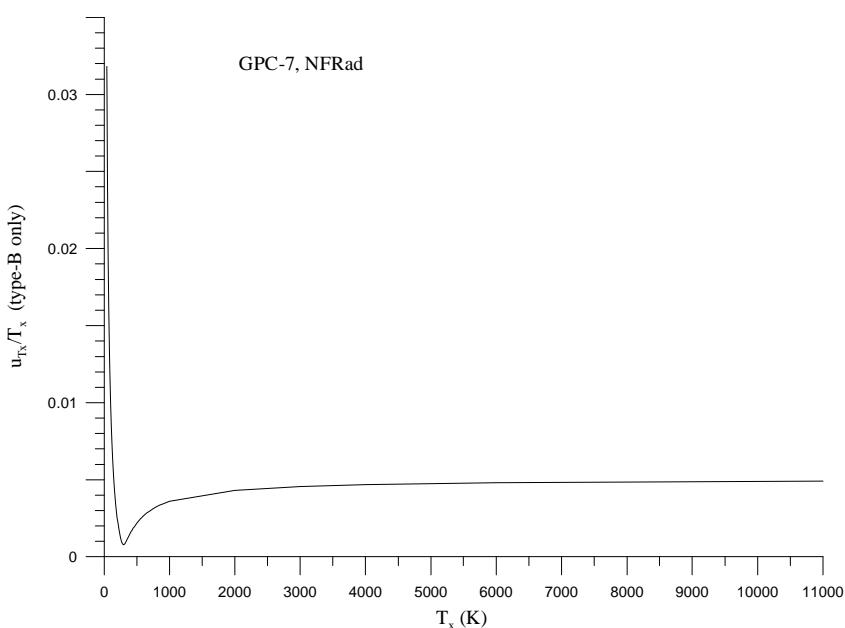
Path Asymmetry: $\frac{u_{T_x}(?/?)}{T_x} \cdot \left(\frac{T_a}{T_x} u_{?/?} \right)$, $u_{?/?}$ ' 0.2% to 0.56%.

Mismatch: $\frac{u_{T_x}(M/M)}{T_x} \cdot \left(\frac{T_a}{T_x} \bar{\sigma}_{M/M} \right)$, $\bar{\sigma}_{M/M}$ ' 0.2%

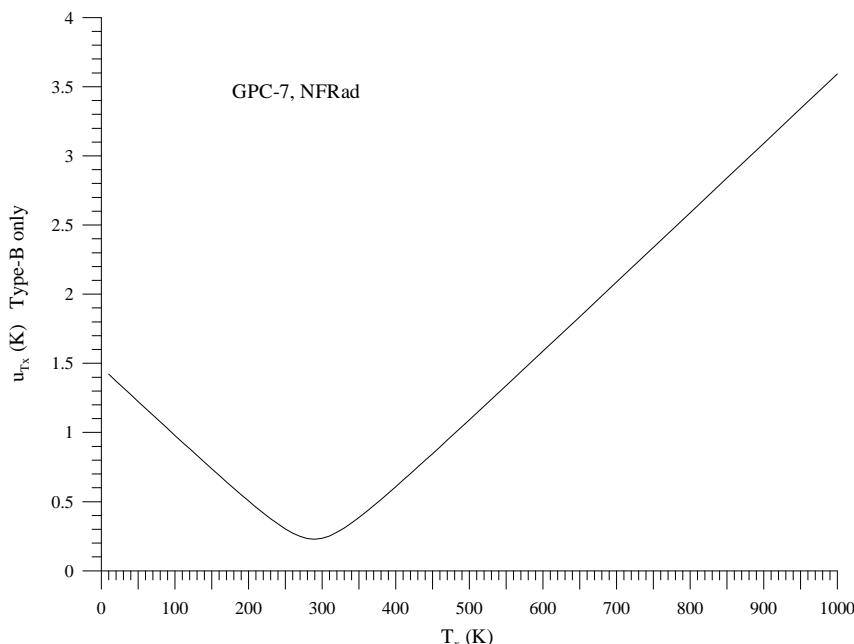
Connectors: $\frac{u_{T_x}(\text{conn})}{T_x} \cdot u_0 \left(\frac{T_a}{T_x} \sqrt{f} \right)$, u_0 ' 0.053% to 0.069%

Nonlinearity, imperfect isolation, power measurement, & broadband mismatch/frequency offset all lead to small (<0.1%) uncertainties (for T_x around 10 000 K).

u_B/T_x as a function of T_x

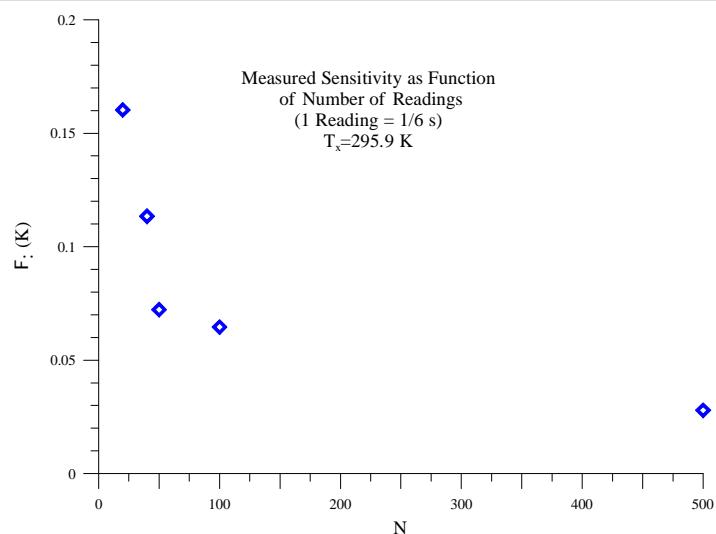


u_B as a function of T_x



Type-A Uncertainty & Sensitivity

- < Negligible for $T_x - 10\,000$ K
- < Significant for $T_x - T_a$, about 0.07 K at 10 GHz for normal configuration (50 readings).



Stability Measurements

Several sources measured

- <Temperature-controlled source from JPL
- <Variable (cold) temperature source from Univ. South Florida (L. Dunleavy) & Raytheon.
- <Commercial diode source.
- <Commercial gas discharge tube.

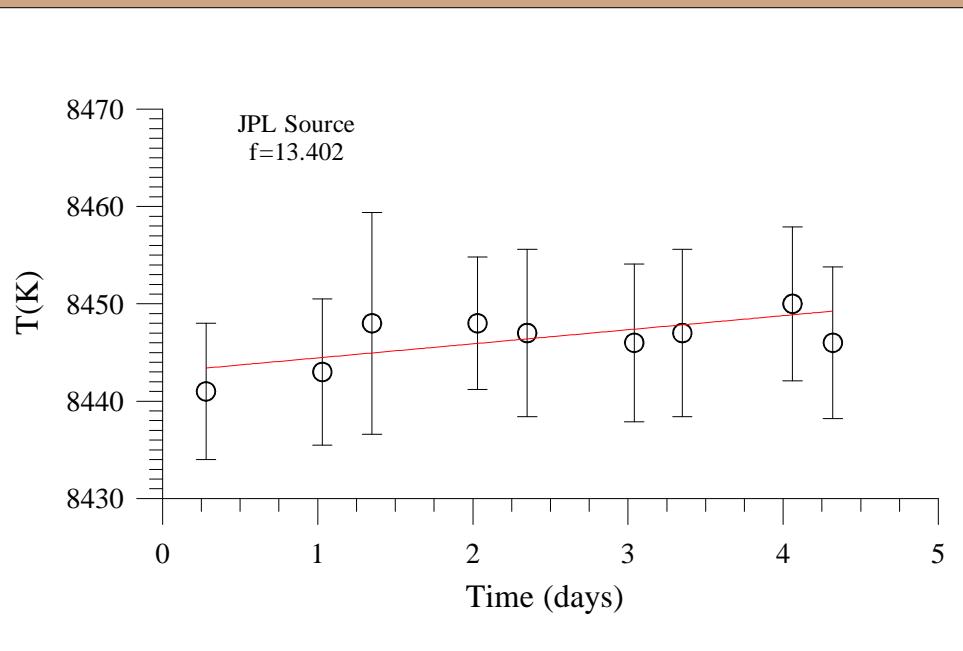
Long (\$1 yr) & short (several days) term stability measured.

As a byproduct, obtained stability measurement of radiometer.

Paper presented at CPEM-2000; to be published in IEEE Trans. I&M.

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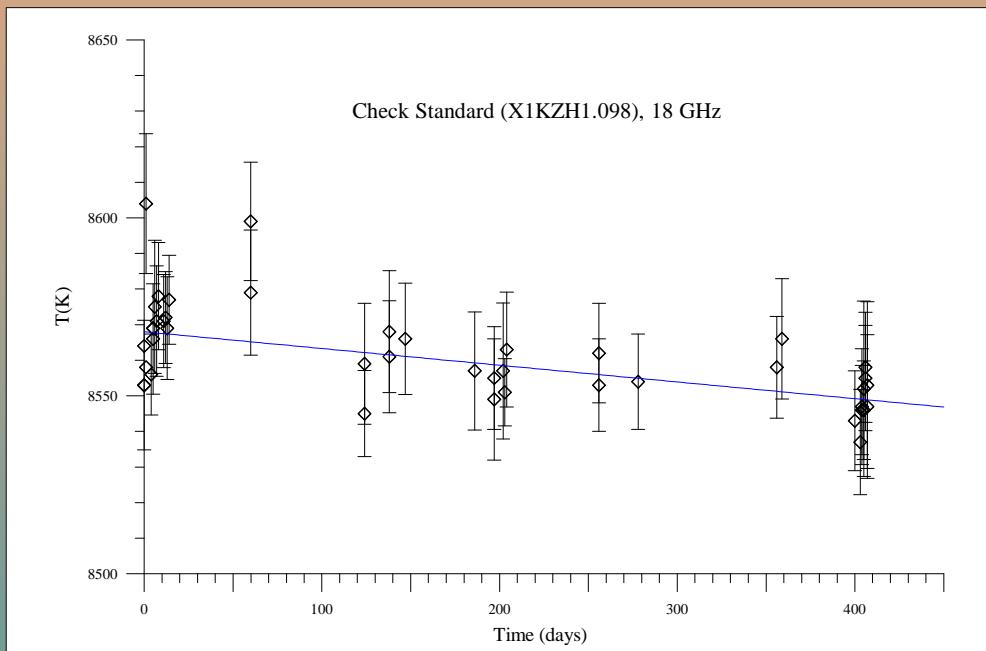
Typical Results



$$\text{Slope} = (0.017 \pm 0.024) \text{ \% / day}$$

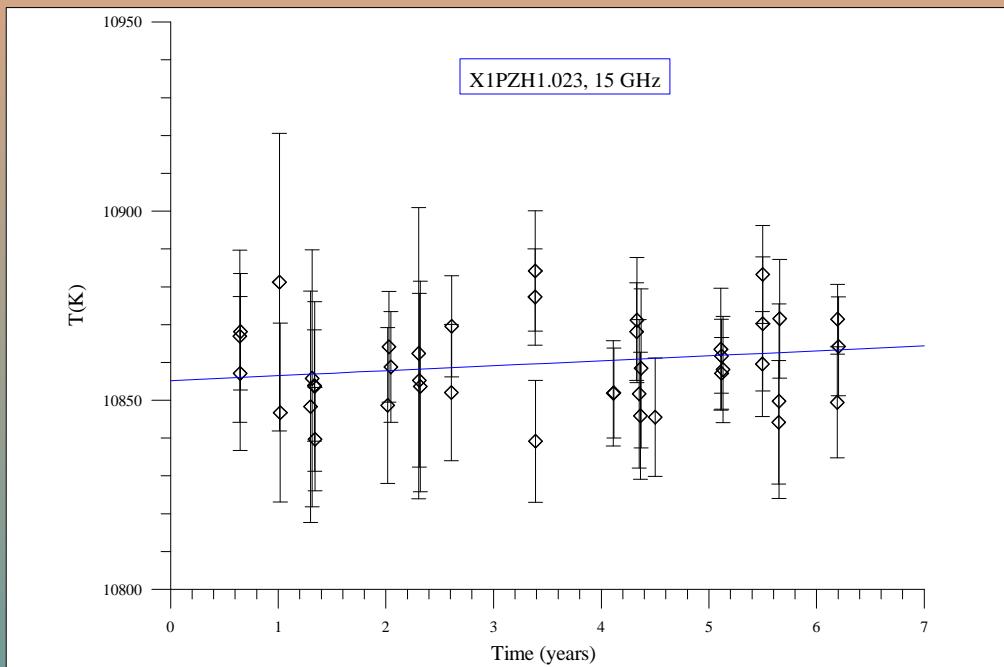
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Typical Results



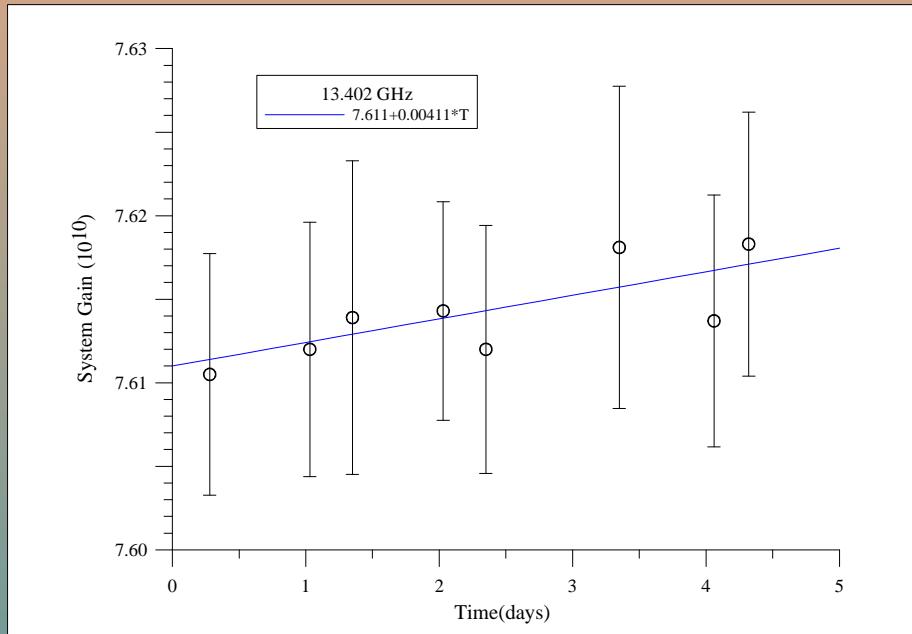
Slope = (0.20 ± 0.05) %/yr

“Typical” Results



Slope = 0.01 %/yr (1.3 K/yr)

System Gain



Slope = (0.019 ± 0.026) %/day

Summary

For more information:

<Ask

<NIST Noise Handouts; include listing of measurement services & recent publications

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